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## SOME CORRECT AND SOME INCORRECT STATEMENTS OF ELEMENTARY CRYSTALLOGRAPHIC THEORY AND METHODS IN CURRENT TEXT-BOOKS

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In optical crystallography the following five terms are used very frequently by nearly all investigators and students: ray, wave-front, wave-normal, refractive index, and vibration direction. The meaning of each of the first three of these terms is understood and there appears to be no confusion in their use. Each of the last two terms is used in two different senses by different authors. As shown in Table I four combinations of meanings of these two terms are thus in use at the present time. The student who reads more than one book therefore almost inevitably enters a state of confusion from which it is difficult for him to emerge. The student is especially handicapped by the fact that scarcely an author (except Niggli) states his usage of both of the terms, refractive index and vibration direction, in a prominent place at the beginning of his treatment of the optical crystallography of anisotropic crystals. The usage of each author (except Niggli) must be searched for in the text. In order to assist students and others who wish to compare the various works of reference the following table has been prepared showing the usage of the terms in most of the treatises on optical crystallography.

Cogent reasons for the usage I are given by Pockels in his textbook. Pockels's definition of refractive index is that appropriate to the statement of the fundamental law of refraction as will appear in the following paragraphs. His definition of the vibration direction is that assumed in the electromagnetic theory as being, of the two possibilities, the more probable one. So far as the authors are aware

TABLE I.

The two different senses in which the term refractive index is used and the two different senses in which the term vibration direction is used in the current treatises on crystal optics.

AUTHOR		USE OF TERM REFRACTIVE INDEX	USE OF TERM VIBRATION DIRECTION
I	Pockels <sup>1</sup>	Reciprocal of wavenormal- velocity	Vibration direction lies in wave-front and is not perpen- dicular to ray.
	Rosenbusch and Wülfing <sup>2</sup>		
	Niggli <sup>3</sup>		
	Johannsen <sup>4</sup>		
	Bouasse <sup>5</sup>		
	Duparc and Pearce <sup>6</sup>		
II	Groth <sup>7</sup>	Reciprocal of ray-velocity	Vibration direction is perpendicular to ray and does not lie in wave-front.
	Dana <sup>8</sup>		
III	<i>a</i> Fletcher <sup>9</sup>	<i>a</i> . . . . .	<i>a</i> & <i>b</i> { Vibration direction is perpendicular to ray and does not lie in wave-front.
	<i>b</i> { Tutton <sup>10</sup>	<i>b</i> { Reciprocal of	
	{ Miers and Bowman <sup>11</sup>	{ wavenormal- velocity	
IV	Winchell <sup>12</sup>	Reciprocal of ray-velocity	Vibration direction lies in wave-front and is not perpen- dicular to ray.

<sup>1</sup> F. Pockels, *Lehrbuch der Kristalloptik*, S. 7, 54, 62, 82, 95 (1906).

<sup>2</sup> Rosenbusch's *Mikroskopische Physiographie der Petrographisch Wichtigen Mineralien*, Bd. 1, Erste Hälfte, 5. Aufl., E. A. Wülfing, 1. Lieferung, S. 85, 86, 91 (1921).

<sup>3</sup> P. Niggli, *Lehrbuch der Mineralogie*, 1. Allgemeine Mineralogie, 2. Aufl., S. 348, 359, 373, 374 (1924).

<sup>4</sup> A. Johannsen, *Manual of Petrographic Methods*, Second edition, pp. 72, 74 (1918). Unfortunately Johannsen's development of the theory is inconsistent with the definitions that he states very distinctly on pages 71, 72. On pages 71, 72 under the heading "Velocity of Any Intermediate Ray in a Uniaxial Crystal" Johannsen writes:

"Let  $r$  = the velocity of the desired ray. . . .

"It is to be noted, however, that the index of refraction of the ray  $r$  is not  $1/r$ , as at first sight one might suppose, but is of a different value."  
and on page 72 under the heading "Velocity of Any Intermediate Wave in a Uniaxial Crystal" he writes:

"Let  $MN=w$ , the velocity of the wave produced by the [parallel] rays  $r$ ,  $r$ .  
 $\epsilon_1$  = the index of refraction of the ray  $r$ .

"Since the disturbance produced by the ray  $r$  results in forming a wave whose velocity is  $w$ , the index of refraction of this wave is the index of the ray producing this velocity, or

$$w = 1/\epsilon_1."$$

On page 81, however, under the heading "The Optical Indicatrix" Johannsen writes:

"If  $MA$  (or  $Mr$ ) represents the velocity of a ray of light, the normal from the vertex of its conjugate  $CM$  (or  $RN$ ) will represent its index of refraction multiplied by a constant."

This is erroneous. On the basis of his definition of refractive index Johannsen should write instead that if  $MA$  (or  $Mr$ ) represents the velocity of a ray of light, its conjugate  $CM$  (or  $RM$ ) will represent its index of refraction multiplied by a constant. The same mistake is made on page 94 in respect to biaxial crystals.

<sup>5</sup> H. Bouasse, *Optique Cristalline Double Réfraction Polarisation Rectiligne et Elliptique*, pp. 4, 176, 177 (1925).

<sup>6</sup> L. Duparc and F. Pearce, *Traité de Technique Minéralogique et Pétrographique*, Première partie, pp. 41, 42, 48 (1907).

<sup>7</sup> P. Groth, *The Optical Properties of Crystals*, Translated by B. H. Jackson, pp. 100, 122 (1910).

P. Groth, *Physikalische Krystallographie*, 3. Aufl., S. 63, 78 (1895).

<sup>8</sup> E. S. Dana, *A Text-book of Mineralogy*, Third edition by W. E. Ford, p. 258 (1922).

<sup>9</sup> L. Fletcher, *The Optical Indicatrix and the Transmission of Light in Crystals*, pp. 32, 54, 55 (1892). Fletcher states that according to the most acceptable form of the solid elastic theory the vibration direction is perpendicular to the ray but that according to the electromagnetic theory it is in the wave-front and not perpendicular to the ray. Fletcher's statements appear to be clear and free from confusion.

<sup>10</sup> A. E. H. Tutton, *Crystallography and Practical Crystal Measurement*, Vol. 2, pp. 877, 878, 879 (1922).

<sup>11</sup> H. A. Miers, *Mineralogy*, Second edition, Revised by H. L. Bowman, pp. 153, 154 (1929).

<sup>12</sup> A. N. Winchell, *The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals*, Second edition, pp. 77, 78, 114, 115 (1931). *Elements of Optical Mineralogy*, Fourth edition, Part I, pp. 91, 154, 155 (1931).

no reasons are given in the books of later date of publication for deviations from the usage of Pockels. Winchell's deviation in respect to the definition of refractive index leads him into a serious error. Thus he<sup>1</sup> states that:

<sup>1</sup> A. N. Winchell, *The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals*, Second edition, pp. 77, 78. *Elements of Optical Mineralogy*, Fourth edition, Part I, p. 91.



"An extraordinary ray traveling in an indefinite direction, such as  $OP$ , has a velocity represented by  $OP$ , and an index represented by  $1/OP$ . Since the area enclosed by the tangents and the conjugate diameters of an ellipse is a constant (which may be assumed equal to one) it may be shown that  $1/OP$  is equal to  $RN$  of Fig. 169."

This statement is inconsistent with his later statement<sup>2</sup> that:

"the wave-normal of the extraordinary ray always occupies such a position that the index of the crystal for the extraordinary ray in the given direction is equal to the sine of the angle of incidence divided by the sine of the angle between the wave-normal and the normal to the surface. That is, if  $\epsilon'$  is the index for the extraordinary ray in a special direction and  $R$  is the angle between the wave-normal of that ray and the normal to the surface:

$$\epsilon' = \frac{\sin i}{\sin R}.$$

Here  $i$  denotes the angle of incidence and  $R$  denotes the angle of refraction of the wave-normal.

Niggli,<sup>3</sup> however, well and truly says that:

"Die Wellennormale des gebrochenen Strahles liegt in der Einfallsebene. Das Verhältniß des Sinus des Einfallswinkels zum Sinus des Brechungswinkels der Wellennormalen ist dem Verhältniß der Wellennormalengeschwindigkeiten gleich.

"Nun haben wir den Brechungsindex als den reziproken Wert der Normalengeschwindigkeit definiert. Ist das Medium I leerer Raum, so ist somit der Brechungsindex  $n_2$  des zweiten Mediums für die betreffende Welle gegeben durch

$$\frac{\sin e}{\sin i} = n_2."$$

Here  $e$  denotes the angle of incidence (Einfallswinkel) and  $i$  denotes the angle of refraction (Brechungswinkel) of the wave-normal.

The statements of Winchell and Niggli are in contradiction since Winchell defines the refractive index of the extraordinary ray as the reciprocal of the ray velocity. The statement of Niggli is the correct one.

<sup>2</sup> A. N. Winchell, *The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals*, Second edition, p. 83. *Elements of Optical Mineralogy*, Fourth edition, Part I, p. 96.

<sup>3</sup> *Lehrbuch der Mineralogie*, I. Allgemeine Mineralogie, 2. Aufl., S. 361. Cf. also Duparc and Pearce, *Op. cit.*, pp. 56, 57.

Another error in optical crystallography is made in the description of the phenomenon of exterior conical refraction in Winchell's "Elements of Optical Mineralogy."<sup>4</sup> This error would be considered by the present authors as an inadvertent slip were it not for the fact that it appears in two drawings, one in terms of rays and one in terms of beams, and is explicitly stated in the text in addition. Moreover, it has now gone through the second, third, and fourth editions uncorrected. The following statement written for Winchell's "Elements of Optical Mineralogy" by L. M. Scofield and N. H. Stearn appears on page 157 along with the two drawings (Fig. 185) just mentioned:

"All rays of light incident at  $O$  (Figs. 183 and 185) at right angles to a section normal to  $OR$  (the secondary optic axis) travel with equal velocities in the direction of the rays, and vibrate in various directions at right angles to their various wave-normals; though their directions of propagation are parallel, their wave-fronts are not, that of one being the circle  $II$ , of another the ellipse  $FS$ , and of all others, ellipses intermediate in curvature between these two limiting forms. . . . Upon emerging from a crystal cut normal to  $OR$  (or parallel to  $cc'$ ) these rays form a continuous hollow cone of light of which  $L'N$  and  $L'N'$  are rays at the extremity of a diameter."

Now it is necessary that a hollow cone of rays exactly the same in form as the cone  $KRG$  enter the crystal at  $O$  in order that the hollow cone  $KRG$  may emerge at  $R$ . This fact has already been stated by Pockels<sup>5</sup> in the following words:

"Äussere konische Refraction. Um die dem *Normalenkegel* entsprechende Erscheinung, die *äussere konische Refraktion*, zu beobachten, muss man dafür Sorge tragen, dass innerhalb des Kristalls sich ein Strahl parallel einer Biradialen  $OR$  fortpflanzt. Da dann in der Kristallplatte unendlich viele, den Normalenkegel bildende gebrochene Wellennormalen existieren, so müssen auch im *einfallenden* Licht unendlich viele Wellennormalen- (oder Strahlen-) Richtungen vorhanden sein, die einen bestimmten Kegelmantel erfüllen, dessen Spitze in der Eintrittsfläche liegt. Gesetzt, es falle ein derartiges Strahlenbündel, wie es bei Umkehrung des Strahlenganges aus dem Biradialstrahl hervorgehen würde, auf eine planparallele Kristallplatte, so bilden die

<sup>4</sup> Fourth edition, Part I, pp. 157, 158.

<sup>5</sup> *Op. cit.*, p. 60.



austretenden Strahlen einen ebensolchen Kegel, indem sie von demjenigen Punkte  $\mathfrak{A}$  der hinteren Plattenoberfläche aus divergieren, in welchem dieselbe von dem singulären Biradialstrahl getroffen wird. (Siehe Figur 25.)"

The necessity for the incidence of a cone of rays, not merely a single perpendicular ray, is a direct consequence of the most elementary principle of geometrical optics. If the parallel-sided crystal plate be homogeneous then for every wave-normal present in the light after emergence there must be a parallel wave-normal present before incidence (the medium on both sides of the crystal plate being one and the same). Although it is not stated that the medium enclosing the crystal plate is assumed to be isotropic this is clearly the intention of the authors since they state that " $L'N$  is the ray of circular wave front, and, since its wave-normal is normal to the surface of the section, it is not refracted upon emergence," which would not be true in general if the enclosing medium were also anisotropic. Now if the enclosing medium be isotropic, such as air or an immersion liquid, then the cone of incident wave-normals must be identical with a cone of incident rays and the cone of wave-normals on emergence also must be identical with the cone of rays on emergence. Thus to obtain the cone of rays of exterior conical refraction on emergence it is necessary that a similar cone of rays enter the crystal plate.

There is one other elementary feature of the description of exterior conical refraction given in Winchell's "Elements of Optical Mineralogy" that is not stated erroneously but is not brought out with the clarity required in view of the fact that several other text-books state it erroneously, for example, those of Johannsen and of Groth. This point is the following. Contrary to the statements<sup>6</sup> of

<sup>6</sup> The erroneous statements in the two text-books mentioned are as follows:

Johannsen writes: "Exterior Conical Refraction. If a section be cut from a biaxial crystal so that the two parallel faces are normal to the line  $Mp$  (Fig. 166), and a ray of light be passed along the line  $Mp$ , it will emerge in the cone formed by the perpendiculars to the planes  $u'$  and  $e'e''$ . Conversely, a cone of light  $ope$ , entering along the secondary optic axis, will pass through along the single line  $pM$ . This phenomenon is called exterior (or external) conical refraction and also was shown experimentally by Lloyd." (*Op. cit.*, p. 102.)

Groth writes: "since at this place there is a conical depression in the outer skin, an infinity of planes can be passed through the point  $M$  tangent to this skin. The normals to these planes, i.e. the rays in the air proper to the several fronts, form an acute cone. Hence, if such a cone of converging rays is made to fall on a plane-parallel biaxial crystal plate cut perpendicular to a ray-axis  $OM$ , these rays, within

Johannsen, and of Groth, the cone of rays in air emerging from the crystal plate does not have the same shape as the cone of the wave-normals inside the crystal plate corresponding to all possible rays traveling along a biradial. In Winchell's "Elements of Optical Mineralogy" it is stated that " $L'N'$  is the ray of elliptical wave-front  $FS$ , and, since its wave-normal is not normal to the surface of the section, it is refracted away from the direction  $OR$ , and follows the direction determined by its wave-normal as a spherical wave upon emergence."<sup>7</sup> The student is likely to be confused, however, by the drawing in Fig. 185 in which the cone of rays (in air) outside the crystal plate has the same letters,  $KRG$ , as the cone of wave-normals inside the crystal plate of Fig. 183, especially since Fig. 183 bears the title "Interior and exterior conical refraction."

Now in the phenomenon of exterior conical refraction the direction of the wave-normal in air after emergence (identical with the ray in air) ( $RG$  of Winchell's Fig. 185) is in general (for every ray except the ray  $KR$ ) different from the direction of the wave-normal inside the crystal plate (the latter is  $RG$  of Winchell's Fig. 183),<sup>8</sup> a conclusion necessitated by the law of refraction stated in the quotation from Niggli given above. It is confusing that these two different directions in Figs. 183 and 185 should bear the same letters.

It should be added that the valuable discussion of exterior conical refraction by Voigt in terms of energy transmission (also taken up in Pockels's<sup>9</sup> "Nachträge"), which explains certain observed details, does not diminish the value of the Fresnel ray surface and the explanation of exterior conical refraction derived from it, and in any event has nothing to do with the objections here raised against the treatments in the books of Winchell, of Johannsen, and of Groth, which continue in force.

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the crystal, are all transmitted along the direction  $OM$  and with equal velocity, and on emerging they are refracted into a similar cone (exterior conical refraction)." (The Optical Properties of Crystals by P. Groth, Translated by B. H. Jackson, y. 141 (1910).)

<sup>7</sup> The phrases "elliptical wave-front" and "spherical wave" are not happily chosen here but the argument need not be lengthened by discussion of them.

<sup>8</sup> If  $RG$  in Winchell's Fig. 183 is not intended to be perpendicular to the ray-surface, i.e., not to represent the wave-normal inside the crystal plate, it was incumbent upon Scofield, Stearn, and Winchell to state this fact; in this case Fig. 183 is a very queer drawing.

<sup>9</sup> *Op. cit.*



It is not unreasonable to ask that the author of an American text-book on crystal optics present the main facts accurately, since there already exist text-books on the subject that are accurate and lucid, for example, Pockels's "Lehrbuch der Kristalloptik."<sup>10</sup> This book may be used or consulted by those who are interested only in the geometrical theory of crystal optics and are not interested in the interpretation in terms of electromagnetic theory since Pockels states in his Preface that:

"Freilich schien es mir, um die Darstellung auch den Kristallographen und Mineralogen leichter zugänglich zu machen, ratsam, die Ableitung aus den Differentialgleichungen nicht an die Spitze zu stellen, sondern sie erst, nachdem die Integralsätze der Lichtbewegung aus einfachen Beobachtungstatsachen mit Hinzunahme naheliegender Verallgemeinerungen entwickelt worden sind, in eingeschobenen Abschnitten nachzuholen, die allenfalls auch vom Leser überschlagen werden können. Diese Darstellung der Theorie hat vor der rein deduktiven zugleich den Vorzug, sich einigermassen der historischen Entwicklung anzuschliessen, sowie die Beziehung zu den Beobachtungen stets hervortreten zu lassen."

The usual methods of determination of the refractive indices of crystalline and other solid substances by immersion of powdered grains in a series of liquids of measured refractive index are described concisely and clearly by Larsen<sup>11</sup> and by Johannsen.<sup>12</sup> Winchell devotes relatively little space to these methods but discusses the index-variation methods in detail. The ease in application of the usual methods, which has already been proved in many places and by many workers, warrants their description in considerable detail in a text-book of crystallography. The majority of measurements of indices of refraction are made for the purpose of the identification of the substance and it is seldom necessary in such cases to vary the composition or temperature of the immersion liquid, or the wave-length of the light used; the greater speed and convenience of the simplest immersion method, by which most of

<sup>10</sup> So far as the present authors are aware the only slip found in Pockels's book thus far is a typographical error on page 23. In the sentence "(Siehe Fig. 10 *a*, *b*, welche den Meridianschnitt der Strahlenfläche für Calomel (+) und Natriumnitrat (—) darstellen.)" the letters, *a*, *b*, should appear in the reverse order.

<sup>11</sup> E. S. Larsen, *U. S. Geological Survey*, Bulletin 679, pp. 12–14, 22–24 (1921)

<sup>12</sup> *Op. cit.*, pp. 258–259.



the actual *determinative* work is done, make it the unquestionable choice in most determinative work. In measuring refractive indices for *record* it is desirable to obtain them with an accuracy of  $\pm 0.001$  or better, which can be accomplished by mixing the liquids, or by variation of the wave-length in the dispersion method, or by variation of both wave-length and temperature in the double variation method. It should be noted that the methods called by Winchell "immersion," "single variation" and "double variation" methods are all immersion methods; moreover, the statement that the limit of accuracy under favorable conditions of the "immersion methods" (the term being used here in Winchell's sense) is about  $\pm 0.003$  is misleading; greater accuracy than this can readily be secured by mixing the liquids until a match is obtained without variation of wave-length or temperature, although when greater accuracy than  $\pm 0.003$  is required it is sometimes more convenient to use the dispersion method or the double variation method.

Winchell's<sup>13</sup> statement: "The technique of measuring indices of refraction by this [dispersion] method is the same as that involved in using the double variation method with the single exception that all measures are made at room temperature . . ." is hardly justified by the facts; the present authors would say that the technique required in the double variation method is more complicated. Although Winchell does not claim that the double variation method is superior in point of accuracy to the dispersion method, he does state that the double variation method is more convenient. On this question there is difference of opinion. Attention should be called to the fact that a very important sacrifice, recognized as a disadvantage by Winchell's collaborator, Emmons, is made in securing the ability to vary the temperature over a range by means of Emmons's apparatus. The variation of temperature is accomplished by means of a water cell between the condenser and the preparation, and according to Emmons this makes it impossible to obtain interference figures in convergent light from the grains the refractive indices of which are being measured. Emmons<sup>14</sup> writes:

"I have been asked if interference figures can be obtained with

<sup>13</sup> The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals, Second edition, p. 65 (1931), or Elements of Optical Mineralogy, Fourth edition, Part I, p. 218 (1931).

<sup>14</sup> *Am. Mineral.*, 14, 425 (1929).

the cell in place. They cannot by any method known to me. Optic axis grains are not difficult to recognize and optic normal grains though not so easy to recognize are less often needed. To measure  $n_p$  and  $n_o$  I believe the standard method is best—namely to choose the grains of highest interference colors in the  $45^\circ$  position and measure a few of them, selecting extreme values. It is to overcome this recognized limitation that I have spent considerable time attempting to adapt the universal stage to this purpose. If successful it should offer an extremely rapid, accurate and generally satisfactory procedure."

Emmons's statement that "optic normal grains though not so easy to recognize are less often needed" deserves careful attention. Without the possibility of using the conoscope (convergent light) to obtain interference figures and unless the universal stage be used, it is impossible to recognize grains oriented perpendicular to the optic normal or to a bisectrix with certainty. Now in all cases it is highly desirable to supplement the purely statistical method of determining  $\alpha$  and  $\gamma$  ( $n_p$  and  $n_o$ ) by checking the orientations of the grains believed to exhibit  $\alpha$  and  $\gamma$ . If the mineral have no cleavage,  $\alpha$  and  $\gamma$  can be obtained by the purely statistical method but one is never sure even in this case that the lowest index,  $\alpha$ , and the highest index,  $\gamma$ , have really been obtained unless the orientation of the grains be established. In cases of minerals with good cleavage the statistical method is unreliable and the student or investigator who relies upon it exclusively in such cases will come to grief sooner or later. How many mica flakes must one examine to find one standing on edge? The case of mica is extreme; between the case of minerals with one perfect cleavage and that of minerals with no cleavage an enormous number of intermediate stages is represented among known substances. The feldspars, for example, are the most important rock-forming minerals and their determination is frequently undertaken by nearly every petrologist. One of the satisfactory methods for accomplishing this is by measurement of the *three principal refractive indices*. The cleavages of feldspars are of such character that in powder one finds that only a small proportion of the grains do not lie on a cleavage face. (For this reason Tsuboi even found it worth while to prepare data for the determination of feldspars by means of the indices exhibited by grains resting on the cleavage planes.) After a statistical search for the lowest index,  $\alpha$ , or highest index,  $\gamma$ , it is imperative in the case of

a feldspar grain that the orientation of the grain believed to exhibit the minimum or maximum index be established, either by means of its interference figure in the dispersion method or by the use of the universal stage in the double variation method as described by Emmons. In the dispersion method the establishment of the orientation of the grain by means of its interference figure involves merely the removal of the eyepiece and a glance down the tube (or if the grain be small the use of one of the numerous special eyepieces available for this purpose).

Accurate and certain results then can be obtained using the dispersion method involving the spectrometer, refractometer, and petrographic microscope, or by the double variation method involving, in Emmons's set-up, in addition to the apparatus required in the dispersion method, the special water cell and, for the reason stated above, the universal stage. An advantage of the double variation method is that all three indices of a biaxial mineral can often or usually be obtained with a single immersion mount whereas more than one mount is usually required in the dispersion method. The preparation of an additional mount requires only a few seconds work in the dispersion method, however. The use of a smaller number of liquids in the double variation method is cited by Emmons and Winchell as another advantage in comparison with the dispersion method. The decision as to the relative convenience of the dispersion method, by means of which much excellent work has been done over a period of years, and the double variation universal stage method of Emmons must be left to the test of time, although the present authors do not believe that the latter is in general as convenient as the former. It is to be noted that finer grains can be handled accurately by the dispersion method than by the double variation universal stage method of Emmons, an important point in the study of artificial materials, which are so often obtained only in a fine-grained condition. Interference figures can be obtained from grains 0.005 mm. in diameter in many cases and 0.01 mm. in nearly all cases in the dispersion method; in the double variation method Emmons<sup>15</sup> claims that grains as small as 0.03 mm. in diameter can be handled with the universal stage.

Winchell<sup>16</sup> writes: "The single variation method (also called the

<sup>15</sup> *Am. Mineral.*, **16**, 554 (1931).

<sup>16</sup> *The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals*, p. 65 (1931). *Elements of Optical Mineralogy*, Fourth edition, Part I, p. 217 (1931).



dispersion method) as proposed by Merwin and developed by Tsuboi, depends upon variation in wave-length (or color) to vary the index of the liquid." This is a serious misstatement of the history of the dispersion method. Merwin and Larsen<sup>17</sup> suggested a dispersion method for use with melts of sulphur and selenium. Later Merwin<sup>18</sup> used and described such a method employing a series of liquids. In the paper to which Winchell refers, Merwin did not merely propose the dispersion method but gave a complete statement of it together with an elaborate application to numerous salts for each of which each index is given for several different wave-lengths in his table of results. On the other hand, Tsuboi<sup>19</sup> did not develop the method but applied it to certain particular cases. No better statement of the facts can be given than that presented by Tsuboi himself at the beginning of his paper in the *Mineralogical Magazine*, which is as follows:

"Recently H. E. Merwin employed an improved immersion method for determining refractive indices to identify certain salts of the system  $\text{Fe}_2\text{O}_3-\text{SO}_3-\text{H}_2\text{O}$ . In the present paper is described an application of the principle of his method to the determination of plagioclases in cleavage-flakes. The following quotation is from the original statement of the method by the above-mentioned writer [Merwin]:

"In the microscopical determinations chief reliance was placed upon refractive index measurements made in standardized media. For obtaining *optical dispersion* a graphical method was used as follows. Along the right margin of a cross-section paper refractive indices from 1.520 to 1.870 were written so that readings as close as 0.001 could be made. A line was drawn across the paper through the middle at  $45^\circ$ ; along this line the refractive index  $n_D$  of each liquid was marked; above and below each such point were placed points, suitably spaced for interpolation, marking the index of the liquid for other wavelengths; points representing a given wavelength were connected.

<sup>17</sup> *Amer. Jour. Sci.*, (4), **34**, 42-47 (1912).

<sup>18</sup> *Jour. Amer. Chem. Soc.*, **44**, 1965-1994 (1922).

<sup>19</sup> *Min. Mag.*, **20**, 108-122 (1923); *Jour. Geol. Soc. Tokyo*, **32**, 1-6 (1925). An abstract of the latter paper (Tsuboi's paper is in English) is given by L. J. Spencer (*Min. Abs.*, **3**, 197 (1926-1928)) and may be consulted by those to whom the Journal of the Geological Society of Tokyo is not accessible.

"Two (or more) refractive indices of a salt under investigation were found with the aid of a monochromatic illuminator, and placed on the plot. The dispersion was read from a straight line through these points. . . ."

Moreover, extensive application of this method was made by Eskola<sup>20</sup> prior to the publication of the work of Tsuboi just discussed. Eskola says:

"In the determination of the refractive indices I had the advantage of using the improved immersion method as worked out by Merwin. This method involves an improvement in accuracy as well as in completeness, making it possible to determine at the same time dispersion as well as refractive indices. One determines directly, using a monochromatic illuminator, the wave-lengths for which the refractive indices to be measured match those of two or more members in the set of refractive liquids. The dispersions of the whole series of liquids used having been determined and expressed graphically, it now remains simply to locate, on the diagram, the points determined and to read the refractive index for any wave-length desired."

In regard to the nomenclature of the immersion method it may be pointed out that the phenomena observed under the microscope with central illumination of powdered grains immersed in a liquid, sometimes called the "Becke line," are improperly so called;<sup>21</sup> the expression, "Becke line," was coined by Salomon<sup>22</sup> to designate the phenomena associated with total reflection at a vertical interface,

<sup>20</sup> *Amer. Jour. Sci.*, (5), **4**, 331-375 (1922).

<sup>21</sup> Cf. the following statement by F. E. Wright: "The method of central illumination is frequently called the Becke-line method while that of oblique illumination is designated the Schroeder van der Kolk method. The papers by Becke and Schroeder van der Kolk were of great importance in emphasizing the significance of these methods in microscopical petrography; but in view of the fact that both methods had been described and applied by Maschke and Thoulet one or two decades earlier and also that in ordinary microscope work (biological, etc.) these methods have long been used and called by the above descriptive terms—central and oblique illumination—it would seem better that these terms be employed in preference to the above. The term Becke-line should be retained, however, for some of the relative refringence determinations in rock thin sections; but in refractive index determinations of crystal grains by central illumination the Becke-line constitutes only part of the phenomena observed, the determination being based primarily on the relative convergence or divergence of the light transmitted through the mineral grain." *Jour. Wash. Acad. Sci.*, **5**, 104 (1915).

<sup>22</sup> W. Salomon, *Z. Kryst. Min.*, **26**, 182 (1895).

which differ in theoretical interpretation from the phenomena obtained with central illumination of irregular grains; the latter are properly known as the central illumination effect.

Winchell, Dana, and some other authors of text-books discuss the symmetry properties of crystals describing three elements, namely, centers, axes, and planes of symmetry. Thus Winchell<sup>23</sup> introduces the student to the subject of crystal symmetry with the following statement:

"All the faces of a crystal, as well as all the constituent atoms, are arranged in accordance with certain elements of symmetry, which are fixed in their position for a given crystal, and determine, not merely its external form, but also the distribution of all the internal physical characters. . . . There are three types of symmetry commonly recognized in crystals, namely, symmetry with respect to (1) a point, (2) a line, (3) a plane. One, two, or three of these types of symmetry may be present in a given crystal.

"A crystal is symmetrical with respect to a point when for each face and edge on one side of the point (or center) there is a similar face and edge directly on the other side of the center. . . .

"A crystal is symmetrical with respect to a line (or axis) when a rotation of less than 360° about this line causes the crystal to occupy exactly the same position in space as at first. If a rotation of 180° produces the first repetition of position, there are two repetitions in a complete rotation, and the line is said to be an axis of two-fold or binary symmetry. . . .

"A crystal is symmetrical with respect to a plane when for each face or edge on one side of the plane there is a similar face or edge directly opposite on the other side, so that one side is the mirror image (in the given plane) of the other."

As an introduction to the subject of crystal symmetry this statement is open to the following serious objection. Axes (rotations), planes (reflections), and centers (inversions) do not constitute a possible minimum set of symmetry elements in terms of which the exterior symmetry of crystals can be described. This can be accomplished by means of either (I) axes (rotations), planes (reflections), and axes of alternating symmetry (rotary-reflections);

<sup>23</sup> The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals, Second edition, pp. 11, 12 (1931) or Elements of Optical Mineralogy, Fourth edition, pp. 3, 4 (1931).



or (II) axes (rotations), centers (inversions), and rotary-inversions.<sup>24</sup> Set I is that used by Fedorov, Tutton,<sup>25</sup> and Groth.<sup>26</sup>

Tutton<sup>27</sup> writes that:

"Pierre Curie, whose name is so familiar to us in connection with the discovery of radium, had previously made it clear that as regards the exterior symmetry of crystals the whole of the 32 classes could only be fully accounted for by admitting as elements of symmetry not only the well-known planes and axes of symmetry, but also a combined plane and axis of alternating symmetry, that is, a new element of symmetry involving a combined rotation about an axis and reflection across a plane, both operations being completed before the second crystal face is arrived at."

This element is termed a rotary-reflection by Wyckoff.

If only axes, planes, and centers be admitted as elements of exterior symmetry, then only one-half of the faces of the general form of the tetartohedral (tetragonal bisphenoidal) class of the tetragonal system can be accounted for. E. S. Dana<sup>28</sup> rightly states that the general form of this class includes 4 faces. The Miller symbols of these faces are:  $(hkl)(\bar{k}hl)(\bar{h}kl)(khl)$ . Dana further rightly states that this class has one binary axis of symmetry, no plane of symmetry, and no center of symmetry. The diagram of Dana further indicates correctly that no horizontal axes of symmetry are present. Winchell and Dana only introduce axes, planes, and centers as elements of exterior symmetry and therefore according to their method the general form of this class should only include two faces and it should be identical with the hemimorphic (monoclinic sphenoidal) class of the monoclinic system; it should then not belong to

<sup>24</sup> The problem here at issue is the statement of the minimum number of symmetry elements necessary to fix the number of faces in the general form and the positions of these faces. The minimum number of symmetry elements at the same time automatically generates all of the remaining symmetry elements of each class. A second and distinct problem is the statement of *all* of the symmetry properties of each of the 32 symmetry classes. The second problem of course cannot be answered without the use of all of the symmetry elements of both Set I and Set II.

<sup>25</sup> Crystallography and Practical Crystal Measurement, Vol. 1, pp. 128-130, p. 135 (1922).

<sup>26</sup> Physikalische Krystallographie, 3. Aufl., S. 311, 312 (1895).

<sup>27</sup> *Op. cit.*, Vol. 1, p. 566.

<sup>28</sup> A Text-book of Mineralogy by E. S. Dana, Third edition by W. E. Ford, p. 90 (1922).

the tetragonal system at all, a fact already pointed out by Rogers.<sup>29</sup> In reality the minimum symmetry requirement of this class is a four-fold axis of rotary-reflection (or a four-fold axis of rotary-inversion) and it does belong to the tetragonal system.

The present authors cannot admit that Winchell and Dana are justified in starting the student off with the idea that axes, planes, and centers of symmetry will serve to explain the exterior symmetry of crystals, especially since the sets of symmetry elements used by the recognized authorities, which are adequate, are not more complicated than the inadequate set described by Winchell and Dana.<sup>30</sup>

Niggli<sup>31</sup> takes Set I as the fundamental elements of symmetry and then shows that a two-fold axis of rotary-reflection gives rise to a center of symmetry and is equivalent to it. Thereafter he uses centers of symmetry in addition to axes, reflections, and rotary-reflections.

Wyckoff<sup>32</sup> gives an excellent brief derivation of the 32 classes from each of the Sets I and II.

<sup>29</sup> A. F. Rogers, *Proc. Amer. Acad.*, **61**, 168 (1926). This statement of Rogers holds true whether one adopts his derivation of the thirty-two symmetry classes or that of Fedorov, Tutton, and Groth. Rogers's derivation given in his paper just cited requires the use of all five symmetry elements of Sets I and II, but in the opinion of the present authors he has not advanced any objection that invalidates the method of Fedorov, Tutton, and Groth.

<sup>30</sup> Dana himself recognized that his method encountered some difficulty as compared with the method in which the symmetry elements of Set I are used; thus Dana wrote: "This method [the method in which the symmetry elements of Set I are used] is not followed here since, though having certain theoretical advantages, it is likely to confuse the student meeting the problems of crystallography for the first time." *A Text-book of Mineralogy*, Second edition, p. 10 (1898).

<sup>31</sup> *Lehrbuch der Mineralogie*, 1. Allgemeine Mineralogie, 2. Aufl., S. 25, 29, 30, 31, 33 (1924).

<sup>32</sup> *The Analytical Expression of the Results of the Theory of Space Groups*, Second edition, pp. 11-15 (1930).

# THE BARINGER HILL, TEXAS, PEGMATITE

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## INTRODUCTION

The Baringer Hill pegmatite lies near the eastern edge of the Central Mineral (Llano) Region (Fig. 1) about 100 miles northwest of Austin, Texas. The nearest towns of any consequence are Burnett, 16 miles east, and Llano, about 22 miles southwest. Access to the pegmatite is by way of a country road from Bluffton, a settlement on the Burnett-Llano highway, about four miles northeast of Baringer Hill. However, this very interesting area is shortly to be submerged due to the development of a hydro-electric project.<sup>1</sup>



FIG. 1. Outline map of Texas showing location of crystalline rocks composing the Central Mineral Region.

The Baringer pegmatite was discovered in 1887 and was the scene of intermittent quarrying until 1907. The leading figure in the mining operations during this period was William E. Hidden who wrote a series of papers describing the local minerals, many of which were new. The deposit was worked mainly for the yttria minerals, which were utilized in the manufacture of glowers for Nernst lamps.<sup>2</sup>

The writer visited Baringer Hill in September, 1930. He was accompanied by Professor Fred Bullard of the University of Texas,

<sup>1</sup> Brown, L. S., A new report on the Baringer Hill district of Texas: (abstract) *Amer. Mineral.*, vol. 15, p. 122, 1930.

<sup>2</sup> Hess, Frank L., Minerals of the rare earth metals at Baringer Hill, Llano County, Texas: *U. S. Geological Survey, Bull.* 340, pp. 286-294, 1908.



to whom he is indebted for many courtesies including the furnishing of the photographs used in figures 2 and 3. Expenses in the field were covered by a grant from the Graduate Research Fund, University of Kansas.

#### GENERAL GEOLOGY

The Baringer Hill pegmatite is intruded into Algonkian (?) granite, which in turn is intruded into the Valley Spring and Packsaddle metamorphic formations. A number of other pegmatites beside that at Baringer Hill occur in the Central Mineral Region, some of which likewise contain rare earth minerals, but no others have been developed to any extent.

Baringer Hill lies on the west bank of Colorado River. Paige describes it as follows: "It is a low mound rising about 40 feet above the river which has here a flood plain about one-fourth mile wide. The hill is formed by an irregular pipe or a short dike of pegmatite which has been more resistant to erosion than the surrounding rock, which is a coarse porphyritic granite with feldspar phenocrysts about an inch long and which disintegrates rapidly."<sup>3</sup>

#### THE PEGMATITE

**GENERAL DESCRIPTION.** The outcrop of the pegmatite is about 100 feet wide and from 200 to 250 feet long, with the longer axis running east and west.<sup>4</sup> At the time of the writer's visit three rock types could be distinguished in the pegmatite. Graphic granite occurs in a peripheral zone several feet thick. Inside of this zone the greater part of the pegmatite consists of masses of pink microcline (perthite) and milky quartz which in places are as great as 40 feet in maximum dimension. Near the center of this coarse quartz-microcline aggregate occurs in a vertical shoot the third type of rock which due to its distinctive red color will hereafter be referred to as "red rock." It is the rock in which the greater part of the rare earth minerals are found.

**ROCK TYPES.** The *graphic granite* has a most striking appearance, being, as Hess has stated, more like the text-book illustrations than the usual graphic granite.<sup>5</sup> The quartz-feldspar ratio varies from about one to one to one to ten, with feldspar much the more abun-

<sup>3</sup> Paige, Sidney, Description of Llano and Burnett quadrangles: *U. S. Geological Survey*, Folio 183, p. 12, 1912.

<sup>4</sup> Hess, Frank L., *Op. cit.*, p. 288.

<sup>5</sup> *Op. cit.*, p. 288.

dant on the average. The feldspar is a microcline-albite perthite, with the albite decidedly subordinate. The latter is much less kaolinized than the microcline. In some hand specimens of the graphic granite the microcline cleavage extends across the specimen. The quartz rods are up to 4 centimeters in length and vary from hair width to one-half centimeter. Thin sections of this rock show microcline in single large individuals which have simultaneous extinction over the entire slide, while the quartz rods do not extinguish simultaneously. Strong evidence for a replacement origin of the graphic granite may be seen in the thin sections. Microcline was the host mineral and it completed its crystallization before quartz was introduced. The evidence that replacement took place follows:

1. "Islands" of microcline occur in quartz with orientation parallel to the microcline "mainland."<sup>6</sup>

2. The quartz is vein-like while the microcline is not.

3. The quartz rods bifurcate and send apophyses into the microcline. They transgress the albite lamellae, as has also been noted by Schaller.<sup>7</sup> Vogt<sup>7a</sup> has recently answered this point of Schaller's by stating that the quartz rods do not cut the albite lamellae, as the latter formed through exsolution (according to Anderson) and stopped at the quartz rods. However, the perthitic albite of the Baringer Hill pegmatite is the "vein" type which both Anderson and Alling<sup>7b</sup> ascribe to either deuteric or hydrothermal activity. It is very definitely older than the quartz. The writer is in agreement with Vogt and Fersman that the elongation of the quartz rods apparently has nothing to do with the planes of weakness of the feldspar, but he disagrees with Vogt's implication that graphic granites can be explained only by a simultaneous crystallization of quartz and microcline. The interdependent crystallographic arrangement of the quartz and microcline described by Fersman might also be obtained through intermolecular replacement.

<sup>6</sup> Bastin, E. S., et. al., Criteria of age relations of minerals: *Econ. Geology*, vol. 26, p. 599, 1931.

<sup>7</sup> Schaller, W. T., Mineral replacement in pegmatites: *Amer. Mineral.*, vol. 12, p. 61, 1927.

<sup>7a</sup> Vogt, J. H. L., The physical chemistry of the magmatic differentiation of igneous rocks. *Skrifter utgit av Det Norske Videnskaps-Akademi i Oslo. I Mat.-Naturv. Klasse*, No. 3, Second Half, 1930, p. 126.

<sup>7b</sup> Alling, H. L., Perthite: *Amer. Mineral.*, vol. 17, p. 60, 1932.

The *normal pegmatite* consists of milky quartz and perthitic microcline. The latter often exhibits square outline (Fig. 2), and continuous cleavage faces extending several feet may be observed. The microcline is visibly perthitic and the percentage of albite is materially greater than in the graphic granite microcline. Some of the



FIG. 2. Microcline crystal surrounded by quartz.

feldspar masses reach dimensions as great as 30 feet, and even larger quartz masses may be observed. A large quartz pillar occurs near the center of the pegmatite which has been left standing as it is practically barren of rare earth minerals (Fig. 3).

The *red rock* differs from the normal pegmatite in that its feldspar is red albite instead of pink microcline. The albite occurs in



thick tabular individuals up to 10 cm. in length and in coarsely granular masses. Microcline, when present, is decidedly subordinate. Quartz occurs abundantly in the red rock in both irregular grains and elongate crystals. The latter tend to parallel the tabular albite crystals, giving the rock a graphic texture, which does not approach the perfection of the peripheral rock, however. Thin sections of the graphic red rock show the presence of albite lamellae, in part transverse to the tabular albite. The writer believes that this transverse albite is older albite which was present in the mi-



FIG. 3. Barren quartz pillar near center of Baringer Hill pegmatite.

crocline perthite of the normal pegmatite, and that the tabular albite has replaced the perthite to such an extent that the original microcline has almost disappeared. Derry has described red albite replacing microcline in the pegmatites of southeastern Manitoba.<sup>8</sup> His albite, however, has a much finer grain than that at Baringer Hill. Cutting through the red rock are abundant magnetite veins. Much less abundant, but largely confined to this rock, are the rare earth and associated minerals.

#### MINERALS OF THE PEGMATITE

**RARE EARTH MINERALS.** The rare earth minerals are quantitatively insignificant, and Hess has estimated that they form but a

<sup>8</sup> Derry, D. R., The genetic relationships of pegmatites, aplites, and tin veins: *Geol. Mag.*, vol. 68, p. 462, 1931.

small fraction of one per cent of the mass of the pegmatite.<sup>9</sup> Consequently it is very difficult to find them in place. Professor Bullard and the writer had their best success in collecting specimens of the rarer minerals from a spot a number of yards southwest of the hill where the miners had cobbled and sorted the minerals. The most abundant of the specimens so obtained was *allanite*. This mineral tends to form large masses rather than veins. One such mass was reported to have weighed over 300 pounds.<sup>10</sup> Surrounding the allanite were albite and radially shattered quartz. *Gadolinite* has been found in masses up to 200 pounds.<sup>11</sup> This mineral is heavy and black in color, as allanite, but differs from that mineral in having an irregular, instead of a smooth conchoidal, fracture. The gadolinite masses collected were associated with cyrtolite, fergusonite, and albite. *Fergusonite* remains fresh longer than the associated gadolinite and albite. It has a typical liver-brown color and a few specimens had a coating of *autunite*. Some of the fergusonite was found in radially shattered iron-stained quartz. *Cyrtolite*, one of the more abundant rare earth minerals at Baringer Hill, is readily distinguished from the other minerals in the pegmatite by its curved crystal faces. It is generally surrounded by albite. Cyrtolite is of especial interest because it is now considered the most important source of hafnium,<sup>12</sup> and the submergence of Baringer Hill will make one of the possible sources of this mineral no longer accessible. Some small grains of *uraninite* (nivenite) were found among the material collected. They were invariably surrounded by a brick-red substance with a resinous luster which has heretofore been called *gummite*. However, it had an index higher than 1.71 which does not accord with the usual published data for gummite.

A number of other rare earth minerals are listed by Hess,<sup>13</sup> including yttrialite, rowlandite, polycrase, and mackintoshite and several oxidation products beside autunite and gummite.

**OTHER MINERALS.** The minerals of the normal pegmatite, *microcline* and *quartz*, are of course of greatest quantitative importance. Where the normal pegmatite lies in contact with the red rock

<sup>9</sup> *Op. cit.*, p. 293.

<sup>10</sup> Hess, *op. cit.*, p. 291.

<sup>11</sup> Hess, F. L., The Baringer Hill pegmatite dike: *Science*, vol. 27, p. 537, 1908.

<sup>12</sup> Lee, Ivan., *Journal Industrial Engineering Chemistry*, news edition, Feb. 10, 1930, p. 10. Abstract in *Foote-Prints*, vol. 3, no. 2, 1930.

<sup>13</sup> *Op. cit.*, pp. 291-293.

the border between the two is a replacive one with quartz and microcline the host minerals (Fig. 4). No orthoclase was noted among the feldspar specimens collected by the writer. *Fluorite* occurs both in the quartz, where crystals measuring a foot across have been obtained,<sup>14</sup> and in the red rock. *Albite* is of greatest abundance in the red rock and it also occurs in crystals lining cavities.<sup>15</sup> One specimen collected by the writer contained a large number of drusy albite crystals with maximum dimensions of two centimeters. *Quartz* occurs in two generations. The earlier quartz is that of the normal pegmatite and the peripheral graphic granite, while the later quartz occurs in the red rock and in crystals in cavities. Re-



FIG. 4. Albite (A) replacing microcline (M) and quartz (Q).

garding the latter occurrence Hidden says: "A cavity into which a horse could have been put was discovered on the river side of the mine and from it a large crystal of smoky quartz was taken that weighed over 600 pounds."<sup>16</sup> Hidden also found amethysts occurring in cavities in feldspar. The only other mineral in abundance in the pegmatite is *magnetite*. It cuts through the red rock in veins averaging about 2 mm. in thickness. Magnetite also occurs in small crystals and in spheroidal granular masses. Thin books of *biotite*, associated with albite, were collected by the writer, but very much

<sup>14</sup> Hess, F. L., *op. cit.*, p. 289.

<sup>15</sup> Hidden, W. E. and Mackintosh, J. B., A description of several yttrium and thorium minerals from Llano County, Texas: *Am. Jour. Sci.*, (3), vol. 38, p. 476. 1889.

<sup>16</sup> Hidden, W. E., Some results of late mineral research in Llano County, Texas: *Am. Jour. Sci.*, (4), vol. 19, p. 427, 1905.



larger masses were found by Hidden: "Masses of biotite four feet across were met with and always indicated the presence nearby of the rare earth minerals."<sup>17</sup> *Ilmenite, lepidolite, hematite, rutile, chalcophyrite, pyrite, sphalerite, and molybdenite* have also been noted as occurring at Baringer Hill.<sup>18</sup>

#### SEQUENCE OF MINERALIZATION

The minerals in the Baringer Hill pegmatite were deposited in definite sequence during two distinct phases. The first of these phases was essentially magmatic, while the second was hydrothermal. The space occupied by the minerals forming during the first phase was in most part space previously occupied by the pegmatite magma with replacement of secondary importance, while in the second phase replacement was the dominant process.

**FIRST PHASE.** The sequence of events during the first phase is considered to have been as follows:

1. Intrusion of pegmatite magma. This magma contained abundant water and other volatile constituents and was presumably a residual concentrate of the magma which formed the surrounding granite. The effect of the volatiles was largely to decrease viscosity and lower the temperature of crystallization so that large crystals could form.

2. Crystallization of microcline, with the formation of crystal outlines in part.

3. Partial replacement of microcline by albite, producing perthite. This replacement was due to reaction between the microcline and the residual very mobile pegmatite magma. Alling<sup>19</sup> calls such perthite deuteric.

4. Crystallization of quartz, forming very large masses toward the center of the pegmatite and replacing the microcline in the peripheral zone in such a manner as to form graphic granite. The evidence for the replacement origin of the graphic granite has already been given.

The crystallization of the quartz completed the solidification of the pegmatite magma through that part of the pegmatite now at or close to the surface.

**SECOND PHASE.** The volatile constituents of the pegmatite mag-

<sup>17</sup> *Op. cit.*, p. 427.

<sup>18</sup> Hess, *op. cit.*, pp. 291-293.

<sup>19</sup> Alling, H. L., *Op. cit.*, p. 54.

ma did not enter into the composition of the minerals formed during the first phase. Consequently, with the crystallization of the pegmatite magma to successively lower depths in the pipe-like intrusive, the residual magma became richer and richer in volatiles, eventually becoming a hydrothermal solution. Some of this solution escaped upward through the pegmatite (the easiest channel of escape) dissolving older minerals and depositing new ones as it did so. Evidences of this hydrothermal activity are the general confinement of the minerals classified in the second phase to a restricted part of the pegmatite (the red rock shoot), their constant association with each other, and the presence of irregular veins and other criteria of replacement which will be described in more detail subsequently. The sequence of mineralization during the second phase was as follows:

1. Deposition of fluorite. This mineral is decidedly veined and otherwise encroached upon by albite.

2. Albitization. Subsequent to the deposition of fluorite, the ascending solutions deposited great quantities of albite, forming the red rock previously described. Fig. 4 illustrates the replacement of quartz and microcline by albite. As would be expected, the solutions dissolving microcline and depositing albite were unable to dissolve the albite in the original perthite. This explains the presence of older albite in the red rock thin sections. Albite is an invariable associate of the rare earth minerals. Similar associations have been described by Spence: "In as far as the writer's own observations on the granite pegmatites of eastern Canada are concerned, soda-rich feldspar . . . is particularly in evidence around the rare element minerals, allanite, cyrtolite, titanite, monazite, etc. Albitization of original microcline in such situation may, therefore, be presumed to have taken place."<sup>20</sup> Albitization was accompanied by cavity formation, due to solution exceeding precipitation in parts of the pegmatite. Various points substantiating the theory that cavities in pegmatites are formed by hydrothermal solution have been given by the writer elsewhere.<sup>21</sup> The large cavity already described and smaller cavities noted by Hidden and Mackintosh<sup>22</sup> were formed

<sup>20</sup> Spence, Hugh S., Pegmatite minerals of Ontario and Quebec: *Amer. Mineral.*, vol. 15, p. 494, 1930.

<sup>21</sup> *Amer. Mineral.*, vol. 10, pp. 364-366, 1925.

<sup>22</sup> *Op. cit.*, p. 476.

during this stage. Some became lined with albite crystals while later solutions deposited quartz crystals in others.

3. Deposition of quartz (second generation) both in the red rock (giving portions of this rock a graphic texture) and as euhedral smoky and amethystine crystals in cavities.

4. Deposition of rare earth and accompanying minerals. The hydrothermal phase was completed with the deposition of the rare earth minerals and magnetite, biotite, ilmenite and other minerals. Undoubtedly these minerals likewise were precipitated in definite sequence, but they are so rarely found in juxtaposition that it was impossible for the writer to work out the details of the sequence. As a general rule the minerals in this final group are confined to the red rock, as in the case of the magnetite veins, although in a few places the depositing solutions worked out into the normal pegmatite and there precipitated. Thus Hess noted the presence of lithium mica in cracks in the quartz.<sup>23</sup> Likewise some of the rare earth minerals were deposited in massive quartz. Where this occurs the surrounding quartz is radially shattered. According to Hidden these "stars" were sometimes 8 to 10 feet across. They always had thorium, uranium or zirconium minerals at the center and thus acted as a guide to ore.<sup>24</sup> In the writer's opinion the best explanation for such stars has been given by Hess and Wells: "The radial cracks surrounding minerals and pegmatites are connected with the growth of minerals. . . . The growth took place faster than the older mineral is replaced, breaking the rock radially."<sup>25</sup>

#### CONCLUSION

The Baringer Hill pegmatite differs from those of New England and the Black Hills not only in suite of minerals but also in its dearth of accessory minerals in the earliest formed pegmatite. Due to the latter characteristic the original pegmatite could be classified as alaskite-pegmatite.

<sup>23</sup> *Op. cit.*, p. 289.

<sup>24</sup> Hidden, W. E., Some results of late mineral research in Llano County, Texas: *Am. Jour. Sci.*, vol. 19, p. 433, 1905.

<sup>25</sup> Samarskite from Petaca, New Mexico: *Am. Jour. Sci.*, vol. 19, pp. 17-26, 1930.

# THE CLEAVAGE SURFACES OF GALENA

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## ABSTRACT

This paper contains comments on certain conclusions drawn by Head in a recent article of the same title. Translation-gliding striae have been misidentified by Head as traces of cubic cleavage. Head has also applied the term "slip planes" to two different features which are really *tear lines* and linear voids. The former are markings on the cleavage surfaces of crystals due to the fact that separation does not take place over the whole area of the break on a single atomic plane, but rather along a single plane for a part of the area and then along another parallel plane for another part of the area, etc. The small surfaces connecting the various levels of actual cleavage are *tear lines*. They possess many of the properties of contour lines on maps.

The present article presents comments on some of the conclusions drawn by Head<sup>1</sup> in a recent paper of the same title. The writer entertains different ideas regarding the nature of some of the features described in the original article.

**TRANSLATION STRIAE.** The 90° lattice pattern observed on the cleavage surfaces and well pictured in Fig. 2 of the original article is not evidence of cleavage planes. On the contrary, it is evidence that the crystal did not cleave along the planes indicated by these traces, although subjected to stresses. The markings are translation-gliding striae indicative of the translation  $T = \{100\}$ ,  $t = [011]$ . These are well known for galena<sup>2</sup> and very easy to obtain. In fact a piece of galena can not be cleaved without also subjecting it to sufficient stress to deform it by translation-gliding.

Anyone wishing to convince himself of the identity of the pattern illustrated need only repeat the classic experiments of Mügge on this mineral or devise simple variants of them. It is especially illuminating to observe the striations in the actual process of formation.

Translation-gliding striae are also known to occur on the natural external surfaces of otherwise normal galena crystals, indicating that the mineral has been deformed by natural processes. In fact crystals so marked first led Mügge to suspect the possibility of translation-gliding in galena and to prove it experimentally.

**TEAR LINES.** It appears that Head has used the term "slip plane" in two different senses and then possibly confused the two. In part,

<sup>1</sup> R. E. Head, The Cleavage Surfaces of Galena: *Am. Mineral.*, **16**, 1931, 345-351.

<sup>2</sup> An introduction on the literature relating to translation-gliding in galena is given in: M. J. Buerger, Translation-gliding in Crystals: *Am. Mineral.*, **15**, 1930, 64.



the term seems to have been used in the technical crystallographic sense of the physical metallurgist to mean "glide plane," but if this is the case this significance is immediately lost sight of in favor of a meaning close to "fault surface" in the geological sense, for Head contends that many of them are open passages, that gases and solutions may travel along them, and that in some cases the openings are closed by deposition. To complete the confusion, Head has applied this term, "slip plane," to at least two distinctly different features. To one familiar with galena, however, Head's photographs and descriptions leave little doubt as to his meanings in each case. In order to clear up the confusion, the two features will be redescribed separately:

The "tree-like surface indications" of Head's Fig. 2 and both the obvious and the more delicate straight and wavy lines of his Fig. 3 are tears between the cleavage levels which are parallel to the plane of the paper. For lack of a better name, these features will be designated *tear lines*. They are present on the cleavage surfaces of many minerals and other crystals having good cleavage and may be studied to advantage on muscovite where the supremacy of the single perfect cleavage eliminates confusion due to other features.

*Tear lines* owe their origin to the fact that cleavage does not take place along a single crystallographic plane of atoms even in crystals possessing such perfect cleavage as muscovite. Instead, the crystal cleaves along one plane over a certain area, then, due to a variety of possible causes, the cleavage continues on a parallel plane at a very slightly different level. The shear or tear connecting the two surfaces, making the entire break continuous, is the *tear line* under discussion. It follows that tear lines must be continuous, running from one boundary of the crystal or lineage<sup>3</sup> to another boundary, or else must close on themselves. In all features the tear lines as seen projected against the flat cleavage resemble contour lines except that there is possibly no necessity of their indicating regularly spaced levels.<sup>4</sup>

<sup>3</sup> M. J. Buerger, The Significance of "Block Structure" in Crystals; *Am. Mineral.*, 17, 1932, 177-191.

<sup>4</sup> By this qualification I do not wish to imply that tear lines do not outline blocks or sheets of definite thickness. In fact, I have previously indicated my belief that crystals are periodically weaker at regularly or periodically spaced levels (M. J. Buerger, The Cause of Translation Striae and Translation Strain-hardening in Crystals: *Proc. of the Inst. of Metals Div., Am. Inst. Min. & Met. Engs.*, 1928, 375-

The contouring nature of tear lines is not evident, except on rather careful study. Casual examination might lead one to believe that they were surface markings which gradually die out. For example, in the photograph given as Fig. 2 of Head's article, the lines appear to be well-defined in the north and east quarters and to continue in a general south and west direction where they anastomose and die out in less striking lines. Apparently the lines do not close like contours in this instance. As a matter of fact, the clearness of the lines in the north and east is due to the fact that the tear lines in this region outline a truly cliff-like region by the coalescence of all of the connected lines (and probably more which are too delicate to photograph) from the south and west. Seen in cliff-like aggregates, tear lines are plainly visible; seen as individuals, they are easily overlooked. Furthermore, whether or not a delicate line will appear visible at all depends on the direction of the incident light. Thus, in the figure mentioned, the continuations of the finer lines may be brought into evidence, supposing a metallographic microscope is being used, by cutting off the normal illumination so that the surface of the galena appears black, and obtaining oblique illumination by means of an adjustable lamp. Under these conditions the tear lines stand out as brilliant threads with proper adjustment of the altitude angle of the lamp. Adjusting the azimuth of the lamp or rotating the specimen allows one to follow the lines to their destinations. The specimen may also be studied to advantage with the aid of a binocular microscope using a sharp source of light. Returning to Head's Fig. 2, the tear lines may be interpreted to mean that high<sup>5</sup> ground, as it were, occurs to the southeast with low ground on the northwest, and that the surface drops from high to low abruptly in two or three cliff-like monoclines near the northeast, but drops very gradually in the central and southwest regions.

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388) and more recently Zwicky has independently come forward with the same suggestion from a different viewpoint (F. Zwicky, On Mosaic Crystals: *Proc. Nat. Acad. Sci.*, 15, 1929, 816-822). By this qualification I merely wish to indicate that I have not studied the distribution of functioning cleavage planes indicated by tear lines in a quantitative way, and therefore, wish to imply no necessary regularity in their spacing as yet.

<sup>5</sup> The words "high" and "low" may have to be interchanged in this sentence, for one can not distinguish high ground from low ground on the map of a surface with which he is not familiar unless the altitudes of the contour intervals are marked. In maps of the earth's surface, of course, we are familiar with the action of drainage and can obtain our clue from this in its various influences.

In the case of galena, three varieties of tear lines are encountered. First, there is a type of line of indefinite direction and no highly developed regularity which may be resolved into alternations of the  $0^\circ$  and  $90^\circ$  cubic cleavages (both at right angles to the cleavage surface being examined). Second, there is a gracefully curved, to an almost straight line of irrational direction. The central line of Head's Fig. 2, the prominent curved line some half inch from the left edge of his Fig. 3, and the faint curved line about an inch from the right edge of his Fig. 3, for example, are of this type. Third, this second type often connects with, branches into, or becomes, a regular straight line running in the rational crystallographic direction [110], i.e., at  $45^\circ$  to the cleavage directions. This type of line indicates either a true {110}, (vertical) cleavage or {111}, (inclined) cleavage. Goniometric studies fail to reveal the angle of inclination because of the diffraction effects from such small surfaces. Tear lines of this variety are clearly indicated at the extreme left of Head's Fig. 2, and faintly in the center of his Fig. 3.

Head's photographs admit of no doubt that what has just been described is one of the things he means by slip planes, for his explanation attached to Fig. 2 runs:<sup>6</sup>

"Shows . . . *tree-like, surface indications of "slip planes,"* which in some cases are open and whose surfaces may be etched and non-reflective or smooth as in slickensides."

And in the text, he says (347-348):

"*There are areas in which the preceding characteristics are well defined but in addition show another set of lines not so strongly marked, but clearly visible, extending diagonally across the cleavage lines* [i.e. referring to the translation-gliding indications discussed above] *at an angle of approximately  $45^\circ$ .*"

Further, on page 348, he says:

"*Reference to Figure 2 shows, in addition to the block cleavage, two sets of irregular, tree-like striations that are equally as well marked as the regular cube face outlines* [meaning translation-gliding striae again]. Close examination of these forms suggests that they indicate planes along which slippage may have taken place and through which solutions or gases may have penetrated the cube mass. In some cases these channels are still open and when exposed by dissection show surfaces that present a pebbly

<sup>6</sup> All italics are mine and are used to distinguish the two features included by Head under the term, "slip planes." Italics refer to tear lines, the rest to other features, M.J.B.



appearance indicative of corrosion. Where these channels have "healed," i.e., been filled or cemented, they present surface irregularities similar to those of the cube blocks."

**VOIDS.** In the unitalicized portions of the quotations just given from Head's paper, the author refers to a feature which is quite different from the tear lines just described. Tear lines can only occur on the cleavage surfaces since they arise simultaneously with the cleaving process. If the sense of the preceding discussion has been grasped, it is evident that tear lines are not major breakage features of the mineral but are essentially minor rents; that they are dependent on the major cleavage and can not exist independently of it. There is, therefore, no possibility of their ever existing as, or developing into, open channels or of having been etched. Head has certainly confused tear lines with some other feature.

This second feature appears to be elongated negative crystal cavities. Negative crystals are of common occurrence in galena, especially in the Joplin galena. The nature of these voids is discussed in some detail in another paper.<sup>7</sup>

The writer submits that in the following passages, Head refers to various sorts of negative crystal cavities, usually to cavities of tabular shape (i.e. tabular openings where an ordinary lineage boundary would be present if the two lineages had ever grown together again after once separating slightly<sup>8</sup>): Page 348:

"Close examination of these forms suggests that they indicate planes along which slippage may have taken place, and through which solutions or gases may have penetrated the cube mass."

and (legend, Figure 2):

"... which in some cases are open and whose surfaces may be etched and non-reflective or smooth as in slickensides."

and page 350:

"In some instances the surfaces were smooth and highly reflective, approaching the condition of block cleavage surfaces. In others, the surface of the slip plane was dull and lusterless and had the appearance of having been etched or corroded."

<sup>7</sup> M. J. Buerger, The Negative Crystal Cavities of Certain Galena and their Brine Content: *Am. Mineral.*, 17, 1932, 228-233.

<sup>8</sup> Lineage boundaries usually run more or less radially from the center of the crystal, and there is a decided tendency, in many instances, for the trace of the lineage boundary in the region of the cube diagonals to run at about 45° to the traces of the two cleavages. In this way, the courses of the lineage boundary traces somewhat mimic the courses of the tear lines.

## THE SPRINGWATER METEORITE

H. H. NININGER, *Denver, Colorado*

In August 1931 the writer received from Saskatchewan, Canada, a meteorite said to have been found in a field near the town of Springwater which is located about 100 miles west of Saskatoon. It was at once evident that this was a pallasite, which in itself was of interest since of the eleven hitherto known pallasites from North America none has come from Canada.

The meteorite weighed 41 lbs. (18,570 grams) and was about the shape one would obtain by cutting a standard baker's loaf through the middle on a plane vertical to its base, and departing about 10 degrees from a right cross section. Its base measuring  $25 \times 20$  cm.,

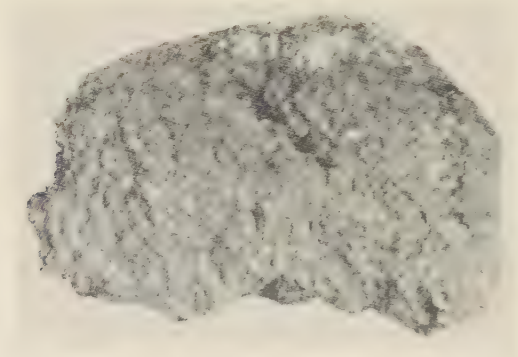


FIG. 1. Side view of Springwater meteorite showing surface pitted by friction in the atmosphere. The white marking at the top represents an incrustation of calcium carbonate.

was in the form of a plane with numerous broad shallow depressions. From this base the two sides and one end arched upward to a height of 14 cm. giving the specimen a rather symmetrical appearance. This convex surface was beset with abundant small pittings in many of which olivine was observed at the bottom. A few areas showed evident traces of furrowing indicative of a steady oriented flight—the furrows always running from the apex or crown of the meteorite toward the margin of its base.

One end of the meteorite showed indications of having been broken, either after its arrival on the lithosphere or during the very last stages of its flight. Here a matrix of fresh-appearing honey-

yellow olivine was beset with numerous jagged, irregular, projections of metal. The metal, except where lately brightened by hammering, was tarnished to a dark rusty brown color.

Except for the more abundant exposure of fresh appearing light colored olivine this meteorite might easily have been mistaken for an individual of the Brenham (Kiowa County, Kansas) pallasite which it strongly resembles externally. However, its structure seemed to be on a smaller scale and the olivine seemed to be more in evidence forming a larger proportion of the mass.

The specimen was cut through near the broken end and five slices,  $1\frac{1}{2}$  cm. thick, were removed all of which show a fairly uniform structure—a more or less complete reticulum of metal em-

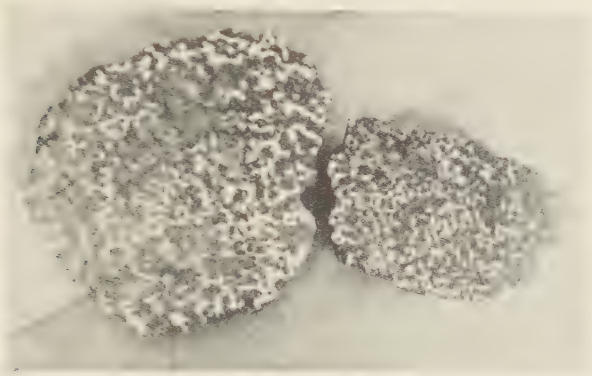


FIG. 2. Showing slices of Brenham and Springwater pallasites side by side.

bracing either singly or in groups, rounded crystals of olivine—a pallasite of the Krsaknojarsk type.

Fortunately, I have at hand for comparison a number of slices of Brenham freshly cut from a large individual of that fall. A comparison of the slices from the two falls shows the following points of difference:

1. The olivine inclusions average about a third smaller in diameter in the Canadian specimen. Typical areas of 27 sq. cm. were selected from the respective meteorites for measurements. In Brenham, this area included 33 olivine inclusions suitable for measurement with an average diameter of 5.5 mm. In Springwater, a similar area gave 49 inclusions suitable for measurement with an average diameter of 3.6 mm.



2. The metallic bands are notably narrower in the Canadian specimen than in Brenham. Six of the widest bands in a slice of Brenham showed an average width of 10.2 mm., while 8 of the widest in a slice of the Springwater meteorite averaged 5.7 mm.

3. The olivine in Brenham, as has been noted by several investigators, is much darker near the surface of a complete individual than in its interior. This shows conspicuously on a polished surface as a darker zone a cm. or more in width around the edge of the slice surrounding the lighter colored olivine of the central portion. Such is not the case in the Springwater meteorite, but in it the lighter and darker olivines are interspersed throughout.

4. The light colored olivine in Brenham shows a faint greenish tinge that is lacking from the lighter colored portion in Springwater.

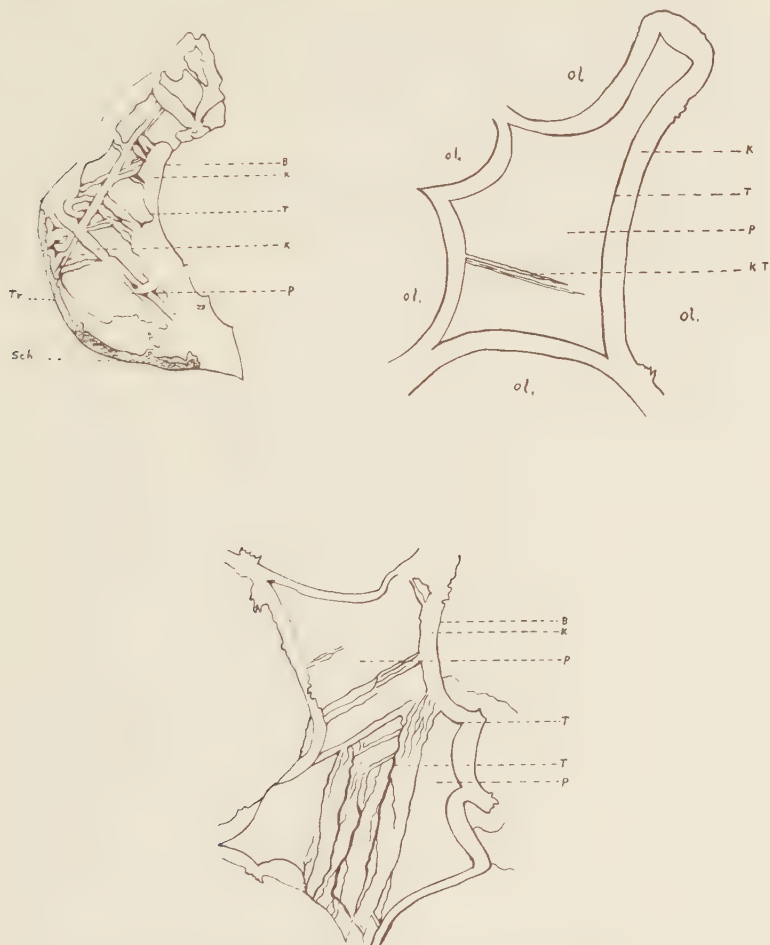
5. The metallic constituent in Brenham comprises a larger proportion of the mass than in the Canadian meteorite, and the reticulum formed by this constituent is correspondingly more complete in the Kansas specimen. In Springwater, areas of several sq. cm. are frequent in which the olivine crystals, though of the usual size, are not separated by metal foliae.

6. When areas such as those just mentioned are found in Brenham, the olivines are nearly always more or less perfectly separated by thin layers of troilite, often quite as perfectly as where the metallic reticulum is present. In Springwater such an arrangement of the sulphide is seldom to be found and never to the degree of completeness that is common in Brenham.

7. The metal of Brenham is very compact, very white, and does not stain seriously in etching with  $\text{HNO}_3$ , if the acid is kept free from the visible inclusions of sulphide. In Springwater, even the briefest treatment with dilute acid produces a sulphide stain on all of the iron. Examination of the metal under a  $10\times$  lens reveals that this is due to abundant minute inclusions of readily soluble sulphide throughout the metallic portion.

8. The etching figures are very much alike in the two meteorites but attain greater perfection in the Brenham where the metallic bands are thicker. In both the border metal is separated from the interior of the band by a bright taenite plate. The figures even where best developed in Springwater, are still much interrupted and very incomplete. The accompanying drawings represent two of the best crystallized areas found.

Schreibersite is present in the Springwater meteorite in about the same distribution and abundance as in Brenham. Troilite however is much less abundant in the former except for the minute inclusions mentioned above. No chromite nor graphite was found.



FIGS. 3-5. Three of the broadest metallic bands showing etching figures.

B, Contact with olivine; K, kamacite; T, taenite; P, plessite; Ol, olivine; KT, kamacite band with taenite border; Tr, troilite; Sch, schreibersite.

The cavities in which the olivines lie are lined by the same highly reflective, mirror-like film as has been noted in the descriptions of Brenham and other pallasites.

Nothing is known of the date of fall of this meteorite. It has evidently lain for many years in the soil. There is not, however, a heavy scale of oxide produced by weathering such as is common on Brenham and many other meteorites. Over much of the surface the original fusion crust is present and in a few places this crust remains unstained, showing clearly the flowage lines characteristic of fresh falls. Over most of the surface however it is completely discolored by a thin film of the products of weathering giving to the mass a rusty brown appearance.

The meteorite shall be known as the Springwater pallasite and is classified as a pallasite of the Krasnojarsk group.

The metallic portion was analysed by F. G. Hawley yielding the following results:

	Per cent
Fe.....	86.65
Ni.....	10.72
Co.....	0.53
Cu.....	0.09
Cr.....	0.025
Mn.....	faint trace
P.....	0.19
S.....	0.30
C.....	0.02
SiO <sub>2</sub> .....	0.44
O.....	1.20
Total.....	100.165
Pt. metals=0.38 oz. per ton.	

Subsequent to the preparation of this description two additional masses of this meteorite have been discovered. One of 23 lbs. weight and the other of 85 lbs. These are in the Nininger Collection of Meteorites.

## NOTES AND NEWS

### AN OCCURENCE OF PICKERINGITE IN ALBERTA

RALPH L. RUTHERFORD, *University of Alberta*

In 1929 the writer made a geological survey of several districts in the Peace River country, Alberta, for the Research Council of Alberta.<sup>1</sup> Some crystalline salts occurring at the junction of the two main branches of the Smoky river in township 77, range 24, west of the 5th meridian, Alberta, were collected. A chemical analysis and optical examination of this material proved the main mineral to be pickeringite. The occurrence of these salts has been known for many years and at different times samples have been sent in for chemical analyses. The fact that they resemble alums has attracted interest in the hope of the discovery of some salt rich in potash.<sup>2</sup>

The salts occur as thin veins and incrustations mixed with clay, along steep slumped banks of the stream valleys where Cretaceous marine shales form the underlying bedrock. Although they occur at several localities, the best known occurrence is that at the junction of the two branches of the Smoky river. They consist of a soft white substance that is readily soluble in water, to which it imparts a bitter astringent taste. Owing to the solubility of the salts, the best collecting time is during the drier summer months. They are formed by decomposition of the marine shales which contain iron sulphides. The shales are generally impervious to water but along steep river valleys the bedrocks become dislodged through slumping. This movement renders the beds more porous, resulting in oxidation of the sulphides and generation of heat. Apparently the water seeping through the loosened material is vaporized and rises in heated condition carrying salts dissolved from the shales and precipitating them at or near the surface as a white incrustation. In the cooler season these vapors often settle in the valley and have been referred to as *bocannes* or *fires*,<sup>3</sup> hence the name, "Smoky river." The heat is frequently sufficient to bake the shales into a brick.

<sup>1</sup> Geology and Water Resources reports of the Peace River and Grande Prairie districts, Alberta: *Research Council of Alberta*, Rept. No. 21, 1930.

<sup>2</sup> Allan, J. A., *Research Council of Alberta*, Annual Report 1920, p. 126, and 1921, p. 39.

<sup>3</sup> Selwyn, R. C., *Geol. Surv. Can.*, Report of Progress for 1875-76, p. 56.



An analysis made from selected material from Smoky river is given in the following table with others for comparison.

## ANALYSES OF PICKERINGITE

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
SO <sub>3</sub>	39.92	36.33	36.32	37.28	37.02	38.69	36.87	36.86	36.43	37.3
Al <sub>2</sub> O <sub>3</sub>	11.90	10.64	12.13	11.85	10.90	11.90	11.64	11.64	13.53	11.9
MgO	6.32	4.79	4.68	4.64	6.75	4.89	4.15	4.18	3.99	4.7
H <sub>2</sub> O	41.35	46.06	45.45	46.10	44.95	41.94	46.07	46.13	44.62	46.1
CaO	..	..	0.13	0.31	1.30	0.68	..	..	0.71	..
FeO	..	0.58 <sup>a</sup>	0.43 <sup>a</sup>	0.03 <sup>b</sup>	..	..	..	..	..	..
Fe <sub>2</sub> O <sub>3</sub>	0.40	..	..	..	..	..	0.26	0.21	..	..
CuO	..	0.02	..	..	..	..	0.18	0.17	..	..
MnO	..	..	..	..	..	..	1.03	1.02	tr	..
K <sub>2</sub> O	..	0.23	..	..	..	..	..	..	..	..
HCl	..	..	0.60	..	..	..	..	..	..	..
Cl	..	..	..	0.02	..	..	..	..	..	..
SiO <sub>2</sub>	0.53	..	..	..	..	..	..	..	..	..
Insoluble	..	0.72	..	..	..	1.90	0.22	0.27	..	..
CoO	..	0.06	..	..	..	..	..	..	..	..
NiO	..	0.14	..	..	..	..	..	..	..	..

<sup>a</sup> includes MnO.

<sup>b</sup> includes CuO and CoO

1. Smoky River, Alberta. T.77-R.24-W5th.
2. Newport, N. S. Dana, System of Mineralogy, page 953
3. Chili " " " " " "
4. Chili " " " " " "
5. Argentine, R. " " " " " "
6. Colorado " " " " " "
- 7 & 8. Portland, Connecticut. Shairer & Lawson, *Am. Journal of Science*, vol. XI, 301, 1926.
9. Bohemia, *Mineral Abstracts*, vol. 3, 354, 1927.
10. Calculated percentage of pickeringite as given in Dana's System of Mineralogy.

The magnesian content of the Smoky river specimens and the general physical properties of it are very similar to those given for pickeringite. A sample was sent to Dr. T. L. Walker at the University of Toronto, who compared it with pickeringite from near Tucumari, New Mexico. He expressed the opinion that part at least of the material from Smoky river is identical optically with that from New Mexico.

Further optical examination and comparison of the material from Smoky river and New Mexico has been made. Some specimens of the Smoky river samples contain more than one salt but the most of it consists of a colorless fibrous mineral with the properties of pickeringite. The individual crystals are too small to determine many of their precise optical properties. They belong to either the monoclinic or triclinic system. Winchell<sup>4</sup> gives the system as monoclinic with the optical plane parallel to {010} and  $Z:c$  equal to 37 degrees. The Smoky river specimens have negative

<sup>4</sup> Elements of Optical Mineralogy, Part 11. New York, 1927.

elongation and a maximum observed value of 35 degrees extinction. Fragments showing the larger extinction angles also show a faint flash figure indicating that the optical plane is parallel to  $\{010\}$ . The index of refraction for the faster ray in sections parallel to the optic plane is almost equal to 1.479 as determined by the immersion method. The birefringence is weak. The aggregates of very fine elongated crystals are usually not commonly optically orientated. Most of the slender crystals appear to be terminated by a cleavage parallel to  $\{001\}$ . Some of the crystal aggregates, where the individual fibres appear to have common optical orientation, have a common cleavage direction which causes the mineral to break into groups of fibres. This appears to be the same cleavage direction as shown by the individual crystals.

It has not been possible to determine with any degree of certainty what the associated minerals are in the Smoky river specimens. Most of the immersion mounts prepared showed one and sometimes two other minerals that are distinct optically from pickeringite. Similarly the New Mexico material also shows mineral impurity associated with the pickeringite. Many of the fragments consisting of aggregates of needle-like crystals have dark patches or zones when examined under plane polarized light. These are believed to be due to fine particles of clay or a similar substance.

The Smoky river pickeringite is formed by the decomposition of marine shales containing iron sulphides. Dana mentions a similar mode of origin for the occurrence of Newport, Nova Scotia. The Bohemian occurrence is also said to be formed as a weathering product of pyritic shales. In these and other occurrences of similar origin it is very likely that more than one mineral would form giving a mixture of several hydrated sulphates. These are usually so fine grained that the individual properties of them are not well known, consequently it is difficult to determine or differentiate them when they occur as mixtures. Pickeringite, however, appears to be one of the more abundant minerals formed by the above process.

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The Council of the Geological Society of America has voted to hold the next annual meeting in Cambridge, Massachusetts, Wednesday to Friday, December 28-30, 1932. The scientific sessions will be held in the buildings of Harvard University and dormitory accommodations will be available on the ground. Arrangements

can also be made for hotel accommodations. The Mineralogical Society and Paleontological Society will hold their meetings at the same time.

Mr. Charles D. Campbell of Ann Arbor, Michigan, has been appointed teaching fellow in mineralogy at Stanford University for the year 1932-33.

Two recent publications of the U. S. Geological Survey that are of unusual interest to all mineralogists are Bulletin 832, *The Crystal Cavities of the New Jersey Zeolite Region*, by Waldemar T. Schaller; and Bulletin 833, *Mineralogy of Drill Cores from the Potash Field of New Mexico and Texas*, by Waldemar T. Schaller and Edward P. Henderson.

The eleventh meeting of the Mineralogical Society of Southern California was held in the Lecture Hall of Pasadena Public Library on Monday, May 9. Dr. William Morris Davis, professor-emeritus of Harvard University spoke on "Illustrations of the Relations of Geography to History." The sixth field trip, held jointly with the geology classes of Pasadena Junior College on May 7-8, included visits to the mines at Borate, Calico and Barstow, and to the vertebrate fossil beds of that region.

Dr. Henry S. Washington, of the Geophysical Laboratory, Washington, D. C., has been elected an honorary member of the Mineralogical Society of Great Britain and Ireland.

George Frederick Kunz, internationally known mineralogist and gem expert, and vice president of Tiffany & Co., died June 29 in his seventy-sixth year. A memorial summarizing the major events of his long and active career will be published in a later issue of this Journal.

## BOOK REVIEW

THE MICROSCOPIC CHARACTERS OF ARTIFICIAL INORGANIC SOLID SUBSTANCES OR ARTIFICIAL MINERALS. ALEXANDER NEWTON WINCHELL, Professor of Mineralogy and Petrology, University of Wisconsin. With a Chapter on the Universal Stage, by Richard Conrad Emmons, Associate Professor of Geology, University of Wisconsin. Second edition. John Wiley and Sons, Inc., 440 Fourth Avenue, *New York*, 1931, xvii+403 pp. Illustrated. 15×23.5 cm. Price, \$5.00.

The appearance of this book marks an important step in the education of the chemical fraternity in the application of the methods developed by mineralogists for the description and identification of crystalline compounds. No one who has had an opportunity to make use of these methods can fail to be impressed with their power and convenience, and the rapidly increasing use of the petrographic microscope in research and industrial laboratories shows that they are appreciated. There has long been a need for a book of tables and synoptic geometrical and optical crystallographic data for crystalline compounds. There is also a need for a text-book of optical crystallography in English that would teach the fundamental principles and main facts, and the methods by which they are applied in the measurement and observation of crystallographic properties.

Winchell's book represents the most complete set of tables and synoptic data for artificial inorganic compounds thus far published and as such will be found very

valuable by all who use the polarizing microscope. This assemblage of crystallographic data constitutes Part II of Winchell's book. Part III comprises a well arranged set of determinative tables based on the assemblage of data in Part II. In connection with Parts II and III the reviewers commend Plate V (in pocket inside of back cover) as a very useful chart classifying artificial inorganic solid substances on the basis of birefringence, optic sign, and refringence. Part I entitled "Principles and Methods" "consists in large part of revised selections from the author's 'Elements of Optical Mineralogy,' Part I, 3d Edition." It represents an attempt to give the reader an understanding or working knowledge of the methods whereby the data of Parts II and III have been obtained and are applied. The phenomena observed in crystals in convergent light are not discussed, however; Winchell refers the reader to his "Elements of Optical Mineralogy, Part I" (Chapters XIV and XVIII) for a treatment of this subject, which of course must be understood by all who intend seriously to use microscopic methods for the description and determination of crystalline compounds. The treatment of crystallographic principles and methods contained in Part I suffers from serious faults, several of which are carried over from previous books by the same author, and some of which are found in other books on crystal optics. A reasonably thorough discussion of these errors requires reference to other text-books and is too long to be included in this review; such a discussion will be found in an article entitled "Some Correct and Some Incorrect Statements of Elementary Crystallographic Theory and Methods in Current Text-books" on page 365 of this issue of the *AMERICAN MINERALOGIST*.

More than half of "The Microscopic Characters of Artificial Minerals" is devoted to a description of the properties of artificial inorganic solid substances (chiefly crystalline compounds) and determinative tables, and the information here assembled, which is available in no other one place, makes the volume invaluable to all who use the polarizing microscope for general determinative work.

The amount of critical judgment that it is fair to expect of an author of tables is difficult to fix. It should be noted, however, that Winchell himself states in the introduction that "the general rule in this book is to give the values of the indices of refraction of pure substances to the fourth decimal place and in three kinds of light (C, D and F). . . . The indices of refraction of some pure substances have not been measured with accuracy and accurate measures have not always been made on strictly pure material; in such cases the indices of refraction are given only to the second or third decimal place." This implies a critical discrimination that has not been carried out.

The inclusion of the inaccurate values of Weber for the three principal indices of refraction of  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  and the exclusion of the accurate and closely agreeing values of Kohlrausch and of Lavenir is illustrative of the lack of discrimination. The inaccuracy of the values of Weber had been pointed out in a paper by Posnjak and Tunell cited by Winchell (p. 228) in connection with the sulphates of copper; Posnjak and Tunell stated, moreover, that the values of Kohlrausch and of Lavenir had been further checked essentially by H. E. Merwin. (Merwin has, however, only published his experimental values for the dispersions of this substance; he has not published his experimental values of the refractive indices. The values of the refractive indices given by Merwin in the International Critical Tables are the mean values of Kohlrausch and Lavenir.) The minimum of discriminative effort required to calculate the optic axial angle from Weber's values of the refractive indices would



have shown the large discrepancy with the measured angle quoted by Winchell; moreover, the value calculated from the indices of Lavenir (similarly that calculated from the indices of Kohlrausch) agrees very closely with the measured axial angle.

Optic Axial Angle, 2V, of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	
46°38'	Calculated from Weber's refractive indices by the reviewers.
56°02'	Measured by Lavenir (and quoted by Winchell).
55°57'	Recalculated from Lavenir's refractive indices by the reviewers.
55°31'	Calculated from Kohlrausch's refractive indices by the reviewers.

Although Winchell states that "The indices of refraction of some pure substances have not been measured with accuracy . . . in such cases the indices of refraction are given only to the second or third decimal place," in the cases of the following compounds he gives more than one set of values of the indices all expressed to four places of decimals but differing among themselves in the third place:  $\text{NaNO}_3$ ,  $\text{KNO}_3$ ,  $\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$ ,  $\text{NH}_4\text{Cl}$ .

Winchell quotes refractive indices of the following compounds to four places of decimals although the measurements were made by means of an indefinite series of wave-lengths through colored screens; several of the values thus obtained are inaccurate in the third place owing to the high dispersions of the compounds and the failure to use monochromatic light. Examples:  $\text{Nd}_2(\text{MoO}_4)_3$ ,  $\text{Ce}_2(\text{MoO}_4)_3$ ,  $\text{CaWO}_4$ ,  $\text{SrMoO}_4$ .

Little or no attention has been given by Winchell to recorded divergences of measurements, or to irregularities in the curves of dispersion or of optic axial angle, 2V, such as are indicated in International Critical Tables, Volume VII. In the following instances Winchell quotes the refractive indices to four places of decimals although plots of the dispersions (or of the measured and calculated axial angles) show such irregularities that the values can scarcely be considered certain in the third. Examples:  $\text{MgO}$ ,  $(\text{NH}_4)_3\text{H}(\text{SO}_4)_2$ ,  $\text{KBF}_4$ ,  $\text{KLiSO}_4$ , and numerous compounds in the series of the types  $\text{R}''\text{R}_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ ,  $\text{R}''\text{R}_2(\text{SeO}_4)_2 \cdot 6\text{H}_2\text{O}$ ,  $\text{R}''\text{R}_2(\text{CrO}_4)_2 \cdot 6\text{H}_2\text{O}$ .

The exercise of critical judgment is of course difficult and laborious and the reviewers do not state that the author of a table is bound to exercise it. The reviewers consider it necessary to point out, however, that the claim made by Winchell that he has exercised such judgment is not made good in his tables. Moreover, he has not taken advantage of careful critical work previously done.

This review may be summarized and concluded with the statement that Winchell's "The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals" contains a very valuable collection of optical and geometrical crystallographic properties to which has been added a rather unsatisfactory account of selected aspects of optical crystallography.

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## PROCEEDINGS OF SOCIETIES

### NEW YORK MINERALOGICAL CLUB

#### *Minutes of the May Meeting*

A regular monthly meeting of the New York Mineralogical Club was held at The American Museum of Natural History on the evening of May 20th, 1931, with an attendance of 68. President Allen was in the chair.

Messrs. J. C. Boyle of Brooklyn, N. Y., H. R. Lee of White Plains, N. Y., and Raymond H. Torrey of Hollis, Long Island, N. Y., were elected to membership. President Allen named the following to serve on the Membership Committee for the ensuing year: Mr. George E. Ashby, chairman, Miss Schroeder and Mr. Grenzig.

Mr. Manchester announced the field meeting to be held on May 30th to the Bedford, N. Y., quarries. A vote of thanks was tendered to Mr. Quinn, Dr. Whitlock's assistant, for his services on behalf of the Club. Treasurer Stanton presented his report which was duly audited and accepted.

The Club was addressed by Dr. Waldemar T. Schaller of the United States Geological Survey on "The Mineralogy of the New Mexico and Texas Potash Deposits." These deposits were discovered during drilling operations for oil at a depth of 1000 feet. Subsequent drilling has revealed the presence of a large potash salt deposit, similar in its mineralogy and origin to the great Stassfurt salt deposits of Germany, but differing in one respect—the German salt beds have suffered considerable deformation while the American deposit has not been disturbed by dyastrophic forces. American potash salts are now being mined near Carlsbad, New Mexico. Dr. Schaller also pointed out that such minerals as sylvite (KCl) cannot be formed directly by the evaporation of sea water, but carnallite ( $\text{KMgCl}_3 \cdot 6\text{H}_2\text{O}$ ) is the mineral so formed. The occurrence of sylvite in the deposit is ascribed to secondary chemical changes subsequent to the original precipitation possibly through the agency of algae. The lecture was illustrated by lantern slides showing photomicrographs of the minerals described as well as samples of the minerals themselves.

Messrs. Manchester and Grenzig reported on the present conditions at the Tilly Foster Mine. Dr. Whitlock discussed differential weathering rings in quartzite as contrasted with rings in agate.

DANIEL T. O'CONNELL, *Secretary*

#### *Minutes of the October Meeting*

A regular meeting of the New York Mineralogical Club was held at The American Museum of Natural History on the evening of October 21st, 1931, with an attendance of 69. President Allen was in the chair.

Mr. John Vlismes of New York, N. Y., and Dr. Ralph W. G. Wyckoff of New York, N. Y., were elected to membership. Mr. Manchester reported upon a successful field excursion of the Club to Bedford, N. Y., on May 30th. He also announced a field excursion for Election Day to the Paterson, N. J. quarries to be led by Mr. Morton, who conveyed to the Club Mr. Mercer's invitation to again visit the famous quarries of which he is in charge.

The meeting was then turned over to the members for reports on their "summer collecting experiences." Dr. Whitlock described how he learned that albite was dichroic, by tests with the dichroscope on peristerite and a moonstone from Ceylon. Dr. Kunz described a remarkable find of succinite amber in the hills of Santiago de los Caballeros, Dominican Republic. Dr. Hawkins exhibited a large collection including emerald, samarskite, cassiterite and uraninite which he secured on his collecting trip to Spruce Pine and Tuxedo, North Carolina. Mr. Radu told of his travels to the Basque Provinces of Spain to learn the art of damascene and to Fortsheim, Germany, to study enameling. He also exhibited a large collection of fine minerals obtained in Germany. Mr. Karlsson exhibited his summer finds collected near home in Connecticut and southern New York, including a large crystal of amazonite from Valhalla, N. Y. Mr. Morton told of his adventures collecting zeolites in Nova Scotia, on the shores of the Bay of Fundy. Mr. Grenzig exhibited choice specimens of marcasite from Cherokee Co., Kansas, and gave a formula for preserving marcasite specimens. He also introduced Mr. John Bucan who found a perfect zircon crystal at Tilly Foster Mine during the summer. Mr. Lee reported on his investigations of the "old gold mine" at Sandy Hook, Conn., and of a reported cryolite locality in Maine. Mr. Maynard brought back some datolite which he found at Westfield, Mass. President Allen described his visit to Brandon, Suffolk, England, where he observed the oldest human industry still extant, that of flaking flint.

At the close of this symposium of "world-girdling" experiences, Mr. Manchester introduced Mr. Peter Zodac, editor of "Rocks and Minerals" magazine of Peekskill, N. Y.

DANIEL T. O'CONNELL, *Secretary*

#### PHILADELPHIA MINERALOGICAL SOCIETY

*Academy of Natural Sciences of Philadelphia, April 7, 1932*

A stated meeting of the society was held on the above date, with the vice-president, Mr. Toothaker, in the chair. Thirty-eight members and forty-eight visitors were present.

Dr. L. C. Wills described "The Preparation of Micro-mineral Mounts." Box mounts of minerals were exhibited at eleven revolving tables carrying microscopes. Among the exhibitors were Dr. L. C. Wills, John A. Grenzig, T. J. Lewis, H. W. Arndt, Dr. W. S. Newcomet, H. W. Trudell, H. E. McNelly, and M. G. Biernbaum.

W. H. FLACK, *Secretary*

*Academy of Natural Sciences of Philadelphia, May 5, 1932*

A stated meeting of the society was held on the above date with the president, Dr. Cajori in the chair. Thirty-three members and twenty-seven visitors were present. Mr. Harold Philip was proposed for junior membership.

Mr. F. Lynwood Garrison addressed the society on "The World's Gold Supply." The history of gold mining was briefly reviewed, introductory to a survey of the present sources of gold. After the discussion, a rising vote of thanks was given the speaker.

Mr. Jackson reported finding aquamarine on the west side of Crum Creek, one half mile above the Media Trolley Line. Mr. Knabe exhibited drusy quartz from Blue Hill, and wavellite from Hellertown. Mr. Gordon described the occurrence of wavellite at an abandoned wavellite mine (worked for fertilizer), on the Tuscarora Creek, 5 miles northeast of Blairs Mills, in Juniata County.

W. H. FLACK, *Secretary*